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ABSTRACT

The communication of research findings among collegiate institutional researchers is considered in relation to the contribution of qualitative language in general, and catastrophe theory in particular. The qualitative language of catastrophe theory may help reduce the arbitrariness of description, through identification of qualitative features that can be simplified in a formal way, and through development of models that can be exchanged and that can lead to further enquiry. Three applications of this language are considered. The first illustrates how the notion of economy of scale can be used to communicate topological, geometric, and algebraic conclusions from the same data. The second begins with the problem of searching for qualitative features in a large amount of data and presents an orderly process for doing this, and the third focuses on the problem of timing in conducting research or in taking action. The applications are arranged in ascending order of dimensionality to show how more complex problems lend themselves equally well to a qualitative mathematical approach. Data from two studies of economy of scale in the nine state universities of Florida are examined, and the qualitative feature of hysteresis is used to explain a critical feature of learning and to suggest other qualitative features of bimodality, inaccessibility, sudden jumps, and divergence. A model relating funding and public confidence in higher education is also presented. The analyses may have value for institutional researchers who need a theoretical model and a qualitative language to exchange qualitative results in order to address more competently larger social and political issues. (SW)

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The Language of Qualitative Issues

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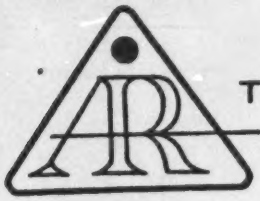

THE ASSOCIATION FOR INSTITUTIONAL RESEARCH

This paper was presented at the Twenty-Second Annual Forum of the Association for Institutional Research held at the Denver Hilton Hotel in Denver, Colorado, May 16-19, 1982. This paper was reviewed by the AIR Forum Publications Committee and was judged to be of high quality and of interest to others concerned with the research of higher education. It has therefore been selected to be included in the ERIC Collection of Forum papers.

D. R. Coleman, Chairman
Forum Publication
Advisory Committee

Abstract

The problem treated in this paper is the communication of research findings among institutional researchers. The central proposition is that qualitative language in general, and catastrophe theory in particular, offer the best hope for formal communication. The method used is a presentation of data from studies which were designed to identify qualitative features and to direct the results to generalizations about economy of scale, information processing, and funding based on public confidence. The results show how institutional research studies can be designed to bring findings to bear on political and social issues using a formal qualitative language.

Introduction

Institutional research has long been concerned with the problem of how to communicate findings among professionals in the field. The data of most studies are, by definition, limited to a single institution, or, at most, to a group of institutions governed by a single board. It is difficult to find a basis for comparing results between single institutional units that employ different definitions, scales, and analytic methods in reports of similar institutional problems. Several suggestions have been made, including Paul Dressel's (1972) view that value identification can provide for exchange, Sidney Suslow's (1972) opinion that a functional approach requires a relationship to the purpose of higher education, or Joe Saupe's (1981) observation that results which have implications beyond the subject of a single institution generally are not sought. The central proposition of this paper is that qualitative language generally, and catastrophe theory specifically, offer the best hope for formal communication among institutional researchers in the next decade.

Three applications of the language are offered as evidence of this proposition. The first illustrates how the common notion of economy of scale can be used to communicate topological, geometric, and alegebraic conclusions from the same data. The second begins with the problem of searching for qualitative features in a large amount of data and presents an orderly process for doing so. The third focuses on a common problem of timing in conducting research or in taking action. The applications are arranged in ascending order of dimensionality to show how more complex problems lend themselves equally well to a qualitative mathematical approach. This approach is used to reduce the arbitrariness of description, to identify

qualitative features in the data which can be simplified in a formal way, and to develop concepts or models which can be exchanged and can lead to further inquiry.

Rationale for Applications of Qualitative Mathematics

Zeeman (1977) suggests:

> The qualitative mathematical language is the natural language for expressing the laws of the social sciences....Now, with the advent of catastrophe theory, this language has suddenly been unexpectedly enriched in two vital ways....First, catastrophe theory has contributed several new qualitatively invariant terms, such as "fold-point, catastrophic change, cusp catastrophe, divergence, normal factor, splitting factor, bias factor, butterfly catastrophe," etc. Second, these new terms are subtle, and have no familiar translation into everyday language. (p. 324)

Since Zeeman (1980) and Johnson (1980) first suggested elementary catastrophe theory for institutional research, several papers have been presented to researchers, including those by Staman (1981) on Catastrophe theory in higher education research; by Cobb and Johnson (1981) on Catastrophe theory: Computer programs for data analysis; by Lacher (1981) on Qualitative mathematical phenomena in a model of decision making; and by Johnson (1981) on Some implications of qualitative mathematical models for institutional research: Basic assumptions and implementation. These contributions add to a growing literature on catastrophe theory that now includes over 700 references which make applications to economics, urban planning, social institutions, psychology, and education.

Purpose

The purpose of this paper is to present three studies, each showing how the qualitative language of catastrophe theory can help formal communication among institutional researchers through reduction in the arbitrariness of description, through identification of qualitative features that can be simplified in a formal way, and through development of models which can be exchanged and which can lead to further enquiry. However, before we discuss the three studies, an explanation of what we mean by "qualitative" is necessary.

Definition

Zeeman (1977) states that all of mathematics rests on the following three types of structure:

1. Order structure--Those analyses which consider "higher" or "greater" use the qualitative concept of order to analyse decisions and to provide sociological meaning.
2. Topological structure--Those analyses which use any kind of continuous scale to describe proximity give sociological meaning to topological concepts, and concepts of calculus, like smoothness, can be used.
3. Algebraic structure--Those analyses which use algebraic concepts like addition and multiplication seldom have any sociological meaning.

Practically speaking, in mathematics, qualitative properties are those that depend on order and differential-topological structures while quantitative properties are those that depend on algebraic structure.

For one-dimensional phenomena, the term "qualitative" can be defined as follows: let x, x' be two one-dimensional scales describing the same data.

If the change of scale from x to x', and the change from x' back to x, is smooth and order preserving (that is, if $\frac{dx'}{dx} > 0$ for all x), then the scales x and x' are said to be qualitatively related. Any statement based upon a particular scale x is qualitatively invariant if the same statement can be made about every scale x' that is qualitatively related to x. Qualitatively invariant conclusions are called qualitative conclusions. Similar definitions may be given for multidimensional scales. Since the change of scale from x to x' can be nonlinear, the order and topological structure of the scales are preserved under the change, while the algebraic structure may not be.

A qualitative language composed of mathematical terms that are invariant under qualitative changes of scale needs to be developed for use by social scientists. If we wish to test our qualitative conclusions, it is necessary to adopt a classical scientific method of choosing an experiment, quantifying each variable, selecting a particular scale, and using a particular method of measurement (Zeeman, 1977). If we wish to compare the conclusions of two different experimenters who have selected two different scales that are qualitatively related, then, while each experimenter may have produced a quantitative graph, only the qualitative properties of those graphs may be meaningful conclusions. The following example on economy of scale illustrates this idea.

A Two-dimensional Application

Economy of scale is a popular concept in business that has been borrowed by institutions. It suggests a relationship between size and cost that does not imply any particular measure or scale. There is no mathematical formula for economy of scale that can be transferred from one situation to another. "The relationship between size and cost is too vague to apply the cost function rigidly to predicting or guiding institutional behavior and

public policy" (Bowen, 1980, p. 179). Economy of scale does depend upon order and topological structure, and thus can be thought of as yielding qualitative conclusions.

Suppose we look at data from two different investigations of economy of scale in the nine state universities of Florida. (The data are from the State University System of Florida Educational and General Allocation for 1978-79.) One researcher, looking for a relationship between cost and size, produced a ratio of allocation (A) to fulltime equivalent students (FTE) for each of the nine universities. Another researcher, who had read Bowen (1980) extensively, produced a ratio of "frontline" (F) to "backup" (B) allocations as an index of efficiency in higher education. The following was produced:

University ranked by FTE	A/FTE	F/B
Florida	1023	1.565
Florida State	1001	1.578
South Florida	802	2.049
Central Florida	879	1.786
Florida International	967	1.695
Florida Atlantic	1322	1.408
Florida A & M	1447	1.285
West Florida	1355	1.382
North Florida	1443	1.305

In order to analyze the relationship between these two studies, the data were first plotted in a linear coordinate system (Figure 1) and then plotted in a log-log coordinate system (Figure 2). Noticing that the "allocation per FTE" index is a monotonic function of the "frontline to backup" index, we conclude that the scales are qualitatively related. In

other words, as A/FTE increases, so does F/B, and as A/FTE decreases, so does F/B. This qualitative relationship is topological in nature and has nothing to do with the linear nature of the graph in Figure 2; it depends on the monotonicity of the graph. Lines are geometric objects, definable only in scaled coordinate systems.

There is a type of "geometric" qualitative conclusion that one can reach from Figure 2 that does have to do with the linear nature of the graph. When data plotted in a log-log coordinate system form a straight line, it follows that one scale is a power function of the other. The power involved is the slope of the line and the constant coefficient a is the intercept. In particular, for Figure 2,

$$\text{slope} = \frac{\Delta \log(A/FTE)}{\Delta \log(F/B)} = -1.388$$

$$\text{intercept} = a = 2023$$

$$(A/FTE) = 2023\ (F/B)^{-1.388}$$

We have now drawn three conclusions:

1. Topological (pure qualitative)--The scales A/FTE and F/B are qualitatively related.
2. Geometric (constrained qualitative)--The scales A/FTE and F/B are related by a power function.
3. Algebraic (quantitative)-- $(A/FTE) = 2023\ (F/B)^{-1.388}$

In circumstances such as these, we believe that we have listed these conclusions in the order of their importance.

We maintain that the typical institutional research conclusion, which is limited to a single system of institutions, gains in application when expressed as a qualitative conclusion relating two scales by their mutual "increasingness" (monotonicity). Other researchers at other institutions can seek this relationship in their data and then refine it to a power

function for their own data.

A Three-dimensional Application

The second project illustrates the common institutional research problem of too much data, too little understood. Simulated learning, particularly when backed by a computer, can produce vast amounts of "printout" material with very little information on what or how the student is learning. In this processing of information study (Fletcher & Hall, 1982), it was hypothesized that the qualitative feature of hysteresis could be used to explain a critical feature of learning and suggest other qualitative features of bimodality, inaccessibility, sudden jumps, and divergence. While Figure 3 shows the interrelatedness of these features, perhaps further (simple) examples found in higher education will help clarify them.

Bimodality (or bifurcation) is the splitting of one behavior into two behaviors. Cuthbert (1981) suggests that when an institution experiences cuts in funding, it can either spread the cuts across the institution equally (squeezing) or it can cut several departments completely to protect the resources of the others (closure). As long as the cuts are not severe, most campus opinion would favor a moderate policy--squeezing some and perhaps a few closures. However, as the cuts become more severe and everyone is affected, opinion would split between those who favor offering a broad base of education through squeezing all departments and those who favor a few areas well done through closure of low quality departments.

Inaccessible region is the behavior between the two emerging behaviors. The behavior is there but no one is displaying it. In the squeezing/closure example, when funding cuts to institutions are extremely severe and everyone is affected, the behavior will be polarized with no one favoring the middle action.

Sudden jumps occur when there is discontinuity in behavior. In the squeezing/closure example, a department that is about to be closed may be given a last minute reprieve because of a rapid change in opinion (the students organize to lobby the legislature) or some other external force (an alumnus donates a large gift to the department to keep it going).

Hysteresis occurs when the same set of circumstances produces two different behaviors, depending on the "direction" one is coming from. In the 1960's, there was a greater demand for teachers than were being supplied by the teacher training programs. By the 1970's, large numbers of teachers were being supplied, but the demand was starting to drop. It is taking most institutions years to slow the supply of teachers to fit the demand. As Figure 4 shows, there were times when the demand for teachers was the same but the supply was either too small or too great, depending upon the decade (direction).

Divergence occurs when a marginal change of path causes a major change in bahavior. Two church-related liberal arts colleges may have minor differences in the composition of their governing boards while being very similar in their policy toward the church. If the difference in the boards is in the number of church-affiliated members, the two colleges will probably be very dissimilar in their policy toward the church several years later.

In the information processing study, Fletcher and Hall (1982) started with "atomic" (simple) behavior based on a two-process theory of human learning proposed and tested by Walter Schneider and Richard M. Shiffrin in 1977. The controlled mode and the automatic mode were considered as processing extremes of a continuous variable P. (The advantage of considering P as a continuous variable is that it may be susceptible to dynamical modelling using differential equations.) Information processing is the capacity of a

person to process incoming stimuli and to react in automatic or controlled mode. A person is said to be operating in an automatic mode when one reacts to stimuli without having to think consciously about each step or what to do next. A person is said to be operating in the controlled mode when one must think about each move necessary to react to a stimulus. For example, turning a corner the first time one drives a car involves thinking about everything one must do--slowing to the proper speed, signalling, looking for oncoming traffic, watching for pedestrians, turning the steering wheel pro= perly, keeping up enough speed to get through the turn, and not hitting the curb (controlled)--while all of this soon becomes automatic with practice.

Fletcher and Hall used a flight simulator to produce novel situations in which moment-to-moment decisions had to be made. The specific object of the exercise was to hold the plane on a straight and level flight heading of 180 degrees. All subjects were given a brief period of time to get used to the machine before increasing levels of turbulance were added and then taken away at each of three levels of engine power. A computer recorded the flight so the researchers could plot the absolute difference in degrees from 180 versus the levels of turbulance for each level of engine power (Figure 5).

While this initial study sought only to find the qualitative feature of hysteresis within the data, Zeeman (1977) talks about the interrelatedness of all five features pictured in Figure 3:

> ...the deep classification theorem of catastrophe theory (stated below) permits us to enunciate the general principle that whenever we observe one of these five qualities in nature, then we should look for the other four, and if we find them then we should check whether or not the process can be modelled by the cusp-catastrophe. (p. 18)

Thom's classification of elementary catastrophes:

Let C be a 2-dimensional control (or parameter) space, let X be a 1-dimensional behavior (or state) space, and let f be a smooth generic function on X parametrised by C. Let M be the set of stationary values of f (given by $\frac{df}{dx} = 0$, where x is a coordinate for X). Then M is a smooth surface in C X, and the only singularities of the projection of M onto C are fold curves and cusp-catastrophes. (p. 23)

Currently, Fletcher and Hall are continuing their research to establish the hysteresis loop in their information processing data, to find the other four qualitative features of the cusp-catastrophe, and to determine the second parameter that causes smooth behavior to be discontinuous (possibly experience related to operating the simulator). Thus, they expect to reduce the arbitrariness of description of human learning through the use of catastrophe theory. They also expect to parallel the behavior of subjects making moment-to-moment decisions with institutional researchers making decisions based on pathways of behavior.

This study is important to researchers for one other reason. It looks at the problem of sequencing--the systematic ordering of presentation of a variable (usually from low to high or high to low). Hillix, Hershman, and Wicker (1979) state that the "powerful effect of sequence is precisely in keeping with the assumptions of catastrophe theory" (p. 43).

Psychological methodologists clearly have recognized the effect of sequence, but their attitude towards these effects has been quite different from those researchers studying catastrophe theory. While psychological statisticians try to minimize sequencing effects they regard as nuisances, they also recognize that current procedures (such as Latin and Greco-Latin squares) may be only partially successful in eliminating these effects.

Winer (1971) seems to sum up the current feelings of authors of popular psychological statistical texts:

> ...in cases where the sequence of administration of the treatment was not dictated by the nature of the experimental variables, it was suggested that order be randomized independently for each subject. A partial control of sequence effects is provided by the use of the Latin-square principle....more complete control is achieved by building what may be called a sequence factor into the design. (p. 576)

Thus, Winer would suggest a systematic order of presentation only when such order is "dictated by the nature of the experimental variables," while the catastrophe theorist would suggest that sequencing is desirable in any case and best when both increasing and decreasing orders are possible.

> We do believe that the philosophy underlying catastrophe theory provides a framework that unites the various types of order phenomena, and a language that helps investigators discuss and understand them. Thus, an understanding of the types of problems with which catastrophe theory deals might lead experimenters to take a new attitude toward the conduct of psychological experiments. Surely there will continue to be a place for experimentation in which values of independent variables are presented in random order, and attempts are made to eliminate order effects. There is also a need, however, for experiments in which many values of independent variables are presented in systematic, ordered sequences. (Hillix et al., 1979, p. 44)

This model allows for more than the exchange of findings about a learning curve. It allows for information about "most recent history" to

play an important part in understanding a phenomena. The prospect of confronting a hand-cart piled with data, with the anticipation of finding something significant, is a familiar specter for institutional researchers. The qualitative approach allows intuition to play an important part in identifying key factors, like hysteresis, and then building an analysis around that feature. If evidence is found of one such feature, the model suggests others which will add insight.

A Five-dimensional Application

The final project deals with the addition of two more dimensions to the cusp-catastrophe. Institutional researchers know that timing is critical to decision-making. Timing is what gets certain legislation passed while other important issues get passed over. Timing plays an important part in job selection, in financial loss or gain, and of course in elections, where the candidates would all like to "peak" on election day. But while everyone talks about timing, doing something about it is another matter. Institutional researchers and administrators would benefit from a model that suggests when the most optimum time to make a decision would be, based on those factors influencing that decision. Figure 6 provides a model relating funding and public confidence in higher education for institutions around the world. The relationships of the variables are delineated in the following hypotheses:

Hypothesis 1--The system can be modelled around a singularity in a gradient-like dynamical system using the dependent (state) variable of public confidence and using the independent (control) variables of power, output, performance, and time.

Rationale--The public policy toward higher education is based on some combination of support for manpower needs, support for free choice of education for all students, support for proven performance showing an

economic advantage to society, and support at a time when attention is focused on the problem.

Hypothesis 2--High faculty power yields high public confidence.

Rationale--When faculty members occupy seats of power (legislature, corporate boards) they are able to control the demand for trained manpower, and when they occupy chairs of power in the university they can control the supply of trained manpower. The degree to which they are able to do both produces a manpower need that will be funded at a level higher than the rate of inflation.

Hypothesis 3--Free student choice of majors lowers public confidence.

Rationale--The public is willing to support higher education if there is an economic advantage. If trained manpower is needed to create this advantage, funding will be provided at a level higher than the inflation rate. If an oversupply of manpower exists, then funding levels will drop below the level of inflation.

Hypothesis 4--Graduates in the job market who demonstrate economic advantage can increase public confidence.

Rationale--The public can be increasingly convinced that liberal arts, non-job-related degree graduates can perform a useful function in society, such as adjusting personal performance to change to avoid job obselescence, and creating new markets for products and services.

Hypothesis 5--Time alters the distribution of public policy.

Rationale--As time passes, the public may grow weary of the issue and the opportunity to adjust attitudes may disappear. An agressive program is the most likely to be effective when performance is strong and the public attention is focused for the time. The model (Figure 6) depicts the time at which an adjustment based on performance can begin.

The first four hypotheses grow out of a three-dimensional application. It is the fifth hypothesis that commands our attention, for it says that there is a time when public confidence can be increased and a time when such efforts would be wasted. Hypothesis 4 has no utility without an appropriate condition for Hypothesis 5 to come into play. The model shows a trimodal distribution of behavior that "opens up" between two extremes of behavior. It is this "porthole to compromise" that is the critical time factor, for without it, only the two extreme behaviors exist. It is not certain that this insight would occur naturally from a typical quantitave analysis. It is a central and expected part of a butterfly catastrophe model (Figure 6).

Conclusions

The implications of this paper hold little for the mathematical development of dynamical systems, of which catastrophe theory is a part. The major value is for practitioners in institutional research who need a theoretical model and a qualitative language to exchange qualitative results in order to address more competently the larger social and political issues of our times. If researchers fail to expand quantitative analyses to reach qualitative conclusions, there is little reason to expect much exchange of information among researchers. In addition, it may well be that administrators, trustees, and legislators better understand a few simple geometric forms than tables of documentation. Since they are complimentary, both should be used to explain and to support a given position.

We conclude that those who ignore the advantages of qualitative approaches are denying themselves, their institutions, and their professions the full range of analysis of a given problem.

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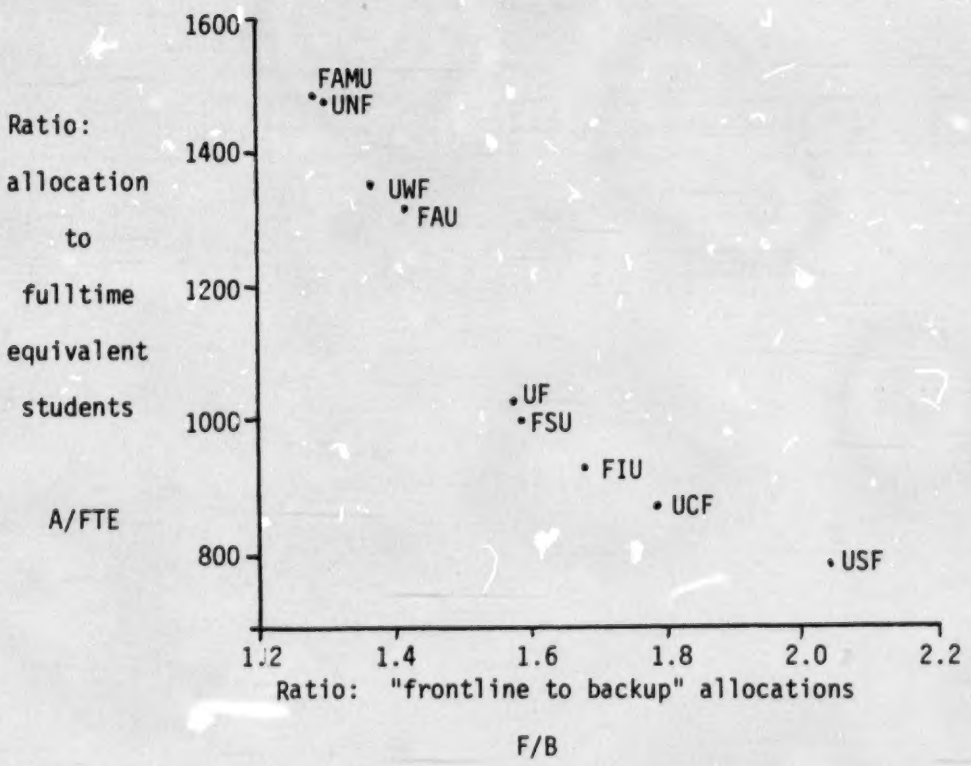
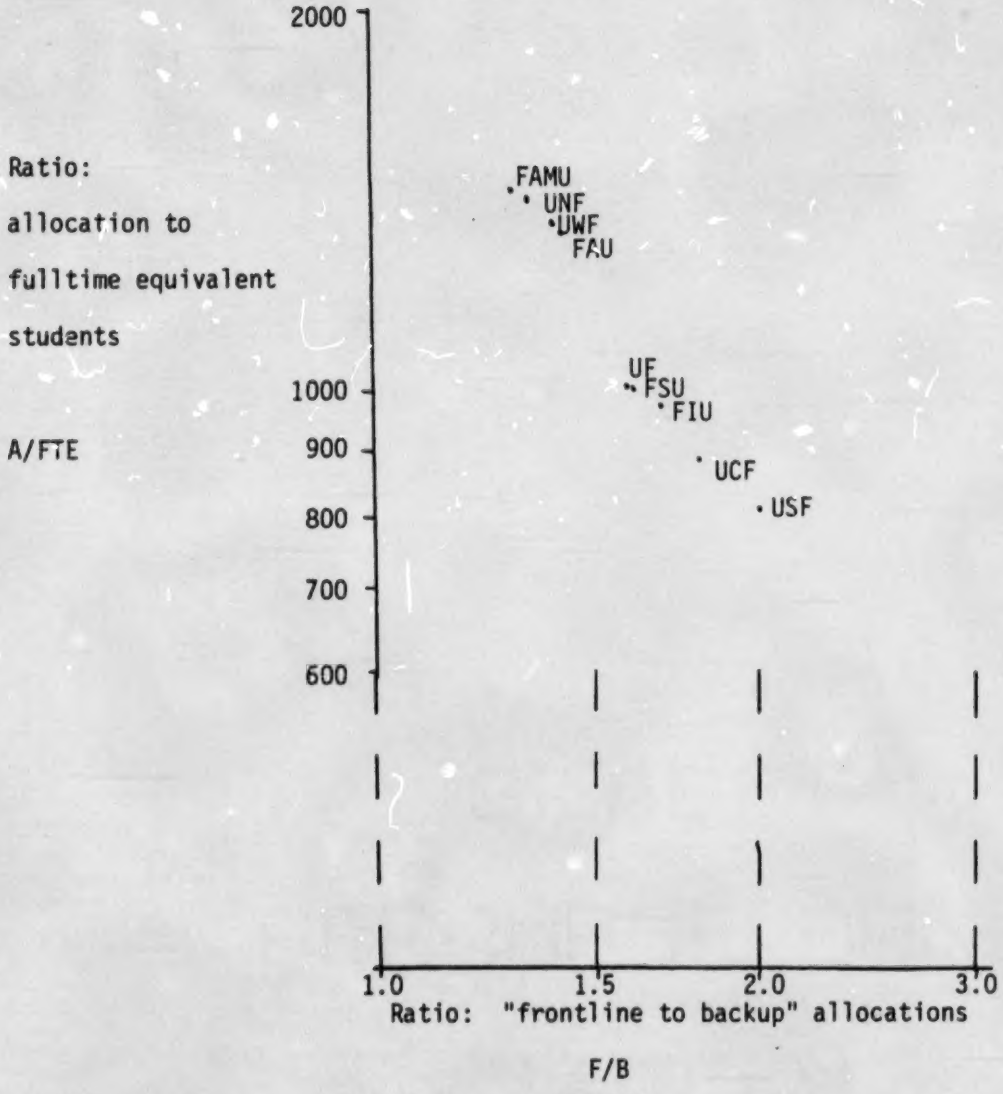
Figure 1



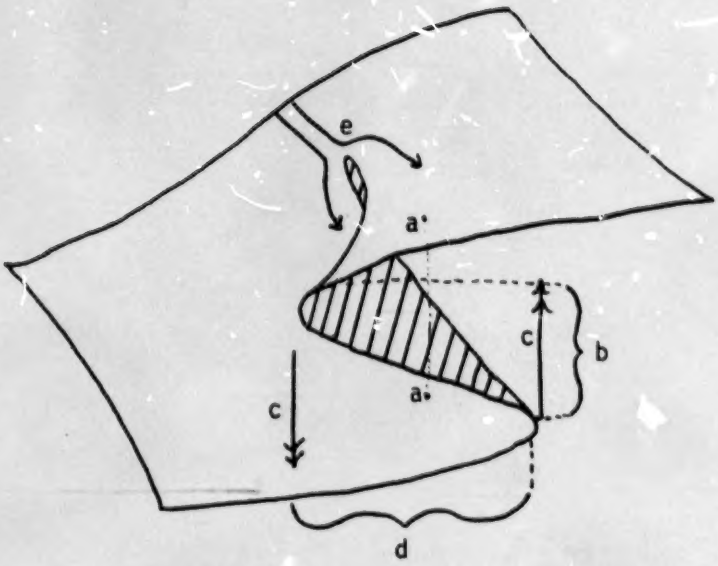
Linear coordinate system graph of the two indices of economy of scale, ratios of allocation to fulltime equivalent students versus "frontline to backup" allocations.

Figure 2



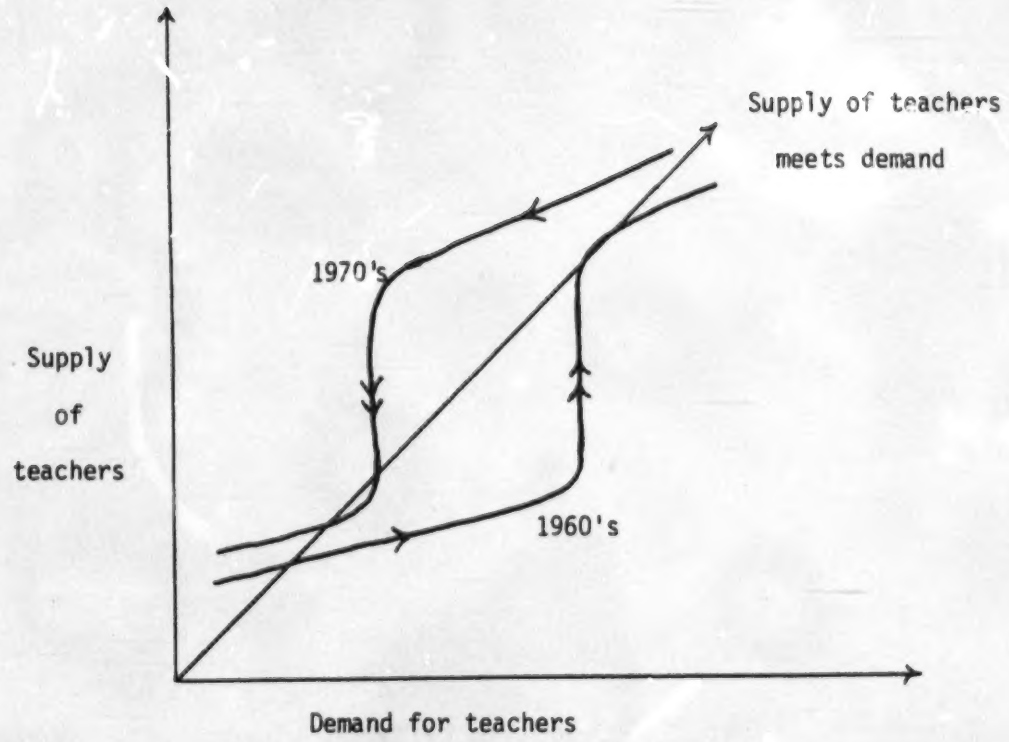
Log-log coordinate system graph of the two indices of economy of scale, ratios of allocation to fulltime equivalent students versus "frontline to backup" allocations.

Figure 3



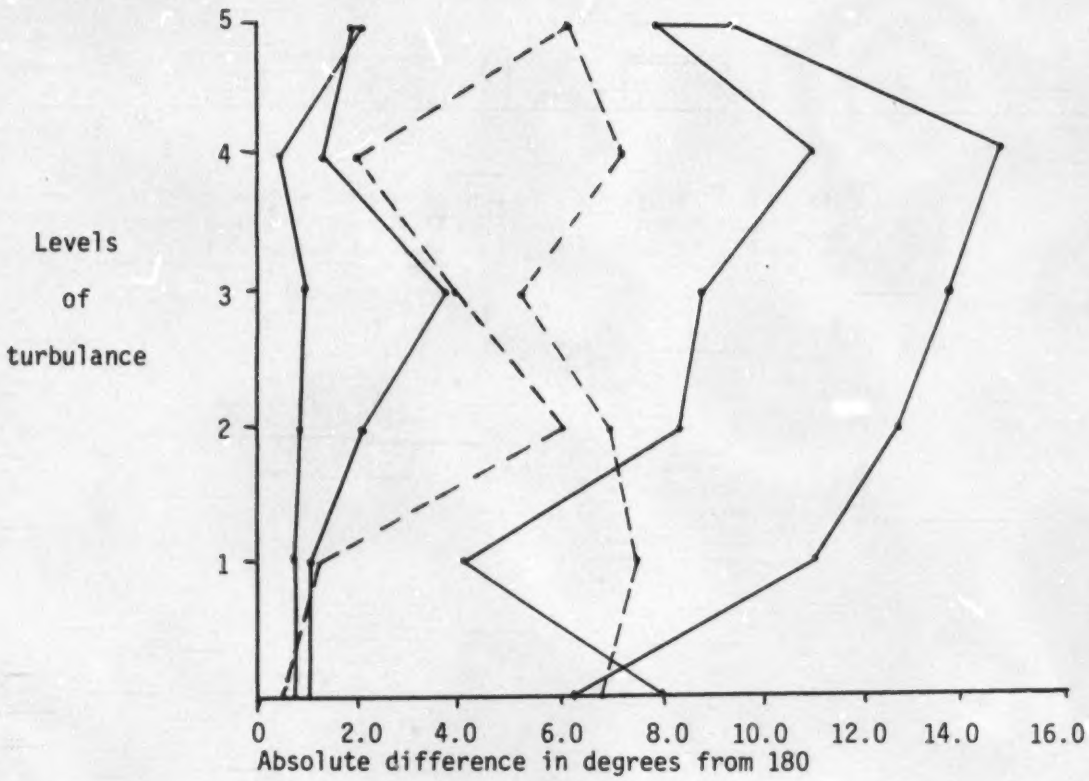
The cusp-catastrophe (top behavior sheet only) showing the interrelatedness of the five qualitative features of bimodality (a), inaccessible region (b), sudden jumps (c), hysteresis (d), and divergence (e).

Figure 4



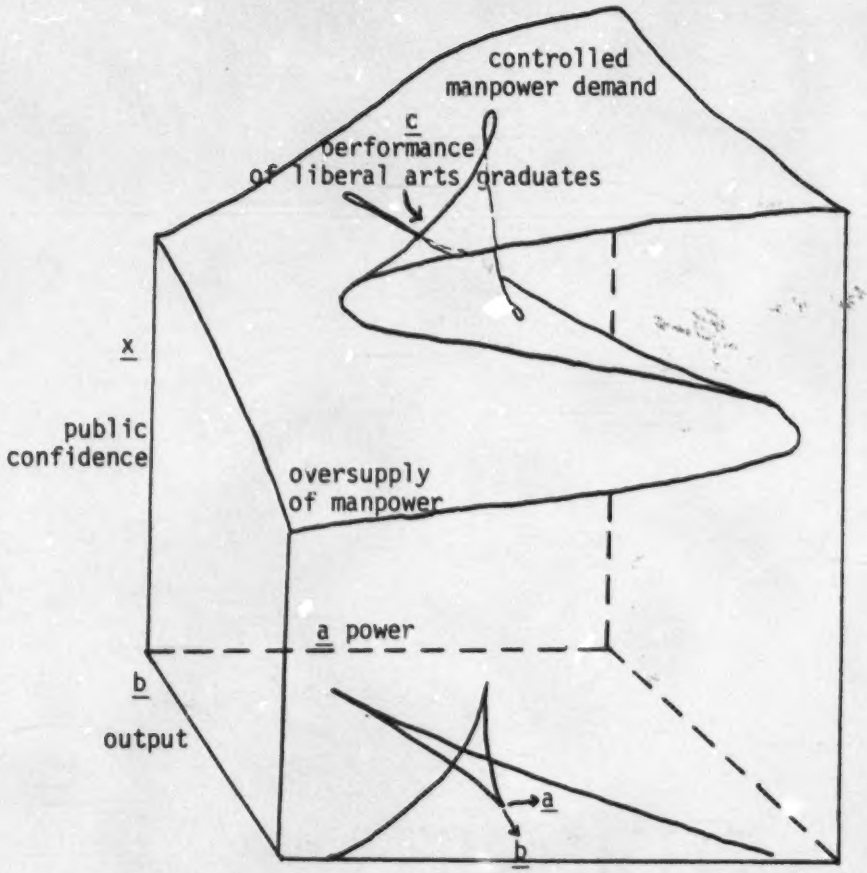
The hysteresis loop shows that there are times when the demand for teachers was the same but the supply was either too small or too great.

Figure 5



Examples of the data collected and plotted by Fletcher and Hall (1982). Data were also kept on the experience of the subjects in driving heavy machinery, stick shift cars, etc.

Figure 6



In this model, public confidence is the dependent (state) variable x (level of support) and the four independent (control) variables are as follows:

a = power (faculty influence on government and the university)

b = output (degrees related to manpower needs)

c = performance (effectiveness of graduates in jobs)

d = time (staying power for public attention)